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(73) Proprietor: S.A. Glaceries de Saint-Roch
Rue des Glaces Nationales, 169
B-5700 Sambreville (BE)

(72) Inventor: Love, Robert Bruce
137 Carnousti Drive
Franklin Tennessee 37064 (US)

(74) Representative: Plucker, Guy et al
OFFICE KIRKPATRICK Avenue Wolfers, 32
B-1310 La Hulpe (BE)

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Description

The present invention relates to deposition systems and more particularly to a method and apparatus for vacuum deposition on large scale substrates in evacuated chambers.

Architectural glass which is transparent yet bears a reflective coating has been found highly desirable for use in buildings to reduce solar heating gains as well as for aesthetic purposes. Minor defects in the coatings are readily observable when the glass is installed and accordingly such glass must be provided with coatings which can be applied reliably without defects and remain securely adhered to the glass when it is in use.

Coating substrates, such as glass, by sputtering atoms of coating material onto them has been found to be an effective process for producing high quality relatively durable coatings. To assure optimum efficiency, the sputtering process should be conducted in a chamber under deep vacuum conditions (e.g., pressures of less than 6,67 Pa). The atmosphere in the chambers should be substantially inert or otherwise chemically controlled, the chamber should be free from contamination and the substrates themselves must be virtually free from surface particles, contaminants, and static electricity to avoid irregularities and/or discontinuities in the coating.

The production of sputter coated substrates has been relatively widely used in the semiconductor industry where small scale production equipment can be used; however, because of the extremely deep vacuum pressures required for high quality sputter coating, production of relatively large scale coated substrates, like architectural glass, has required usage of large, expensive pressure vessels and production rates have been relatively limited.

An example of production equipment for coating small scale substrates is disclosed by U.S. patent No. 3,294,670 in which substrates are coated on a continuous production basis. These kinds of production facilities are constructed using minimum volume internal vacuum chambers so that appropriate pumps can evacuate them quickly and efficiently. Because of the relatively small size of the equipment the vacuum chamber wall areas are small and not subjected to great differential pressure forces. The continuous production technique tends to minimize the possibilities that substrates will be carrying surface dust, moisture, etc. when entering the sputtering chamber because the substrates can be individually cleaned just before the sputtering takes place.

Another example of apparatus for coating small size substrates, such as semiconductor chips, is disclosed in U.S. Patent 3.521.765. This patent aims to eliminate presure gates between internal chambers and teaches the advantages of a continuous conveyor system extending through a series of openly communicating chambers. The access and exit chambers are cylindrical and the substrates are moved from the access chamber into the coating section after reducing the pressure in the access chamber to a value equal to the pressure maintained in the coating section. An important feature of the apparatus disclosed in U.S. Patent 3.521.765 is that the access chamber volume is mechanically reduced before pumping the remaining atmosphere in it. It is obvious that this volume reduction operation could not be effected with large substrates.

Systems have been proposed which utilizes a series of identical in-line chambers with gates between them. In the IBM Technical Disclosure Bulletin (vol. 11, No. 7, December 1968, pp. 757-758), a double-chamber system is used for introducing and removing of substrates from the apparatus, to prevent contamination of the coating chamber. It can be seen that all the chambers have identical volumes each time that the entrance chamber is opened to introduce a new substrate, the entrance chamber has to be pumped down from atmospheric pressure to a suitable coating pressure, what takes much time and limits the production rate.

GB-A-1,189,714 discloses a method and apparatus of depositing material on large size substrates such as architectural glass lights at extremely low pressures. The method comprises the steps of :

(a) moving a substrate into an access chamber isolated from an isolation chamber by a pressure gate, and evacuating said access chamber to a first vacuum pressure level of a few pascals,

(b) communicating said access chamber with said isolation chamber residing at a second vacuum pressure level lower than the first vacuum pressure level, to thereby produce an intermediate vacuum pressure level in said communicated access and isolation chambers,

(c) advancing the substrate into said isolation chamber, isolating said access and isolation chambers, and evacuating said second chamber by diffusion pumping to said second vacuum pressure level which is a few millipascals

(d) communicating said isolation chamber with a coating chamber isolatable from said isolation chamber by a pressure gate, said coating chamber being maintained before communication at a vacuum pressure level which is suitable for vapour deposition and after isolating the coating chamber establishing a vacuum pressure level therein suitable for vapour deposition; and

(e) advancing the substrate into said coating chamber, isolating it and depositing material by vapour deposition on said substrate.

The apparatus comprises :

(a) a working chamber comprising a coating chamber section and, on each side, an isolation chamber section;

(b) an access section adjacent each isolation chamber section and formed by a rectangular pressure wall structure extending closely about the substrates to minimize the pumping volume of said access chamber and provided with mechanical vacuum pumping means for evacuating said access chamber to a first, vacuum pressure level, of a few pascals;

(c) structure defining pressure gates between said chamber sections, between said access and working chambers and between said access section and ambient atmosphere;

(d) said isolation chamber section being provided with first diffusion pumping means for evacuating said isolation chamber section from said first pressure level down to a few millipascals when the pressure gate separating it from the access chamber is closed;

(e) said coating chamber section is provided with second diffusion pumping means for evacuating it;

(f) a conveyor system for supporting and moving substrates through said chambers via said gates;

(g) the inlet access section comprises two chambers, an inlet up-to-air chamber and a glow discharge chamber twice as long as the inlet chamber, to contain two successive glass sheets, whereas the exit access section only comprises a single up-to-air exit chamber. The glow discharge chamber comprises an inlet for an ionizable gas.

When large scale substrates are to be sputter coated, problems arising from inefficient use of vacuum pumps, large chamber volumes and extreme differential pressure forces are encountered. Relatively large chamber volumes are necessitated by the substrate sizes and the chambers are thus not quickly evacuable to coating pressure levels of 6,67 Pa or less. Different kinds of vacuum pumps must be operated in stages to evacuate the chambers to optimum coating pressure levels.

Mechanical vacuum pumps are effective to evacuate the chambers so long as the gas being pumped exhibits fluid flow characteristics. At pressure levels of from 93,33-66,67 Pa the efficiency of the mechanical pumps is reduced dramatically because the movement of the remaining atmosphere in the chambers begins to take on molecular flow characteristics. This results in substantial reductions in pumping speed as the chambers continue to be evacuated to about 26,67 Pa. Diffusion pumps can then be used to further evacuate the chambers to desired lower pressure levels.

Diffusion pumps, such as oil diffusion pumps, are ineffective when operated at pressures over 26,67 Pa and therefore the chambers have had to be mechanically evacuated to the effective operating range of the diffusion pumps. The time taken to reduce the chamber pressure from 66,67 to 26,67 Pa has been significant and reduces coating production rates appreciably.

In the preferred embodiment of the process of this British Patent, pressure is reduced in the inlet access chamber from atmospheric down to about 6.6 Pa. In the glow discharge chamber pressure is maintained at about 2.6 Pa and temperature is raised to 95-380°C. In the inlet isolation chamber, pressure is reduced by diffusion pumps down to a few millipascals. Finally, in the coating chamber, coating takes place at a pressure which is maintained at or below that of the isolation chamber. On the exit side, pressure in the exit access chamber rises to about 6.6 Pa when communicated with the exit isolation chamber and then to atmosphere, when the exit gate is opened.

This Patent concerns coating by means of the thermal evaporation process and all the chambers are of rectangular shape with proportionate reinforcement structures. The coating chamber, which has to withstand a pressure of ten tons per square meter and which is of a large size in order to include the point sources of the thermal coating process, that have to be held at a certain distance from the target to be coated, must therefore be foreseen with considerably strong reinforcements at close-by distances and can only be evacuated by several (twelve) diffusion pumps with relatively narrow openings in between the reinforcement beams.

Some production facilities for sputter coating relatively large glass lights have been proposed in which the glass is supported by racks in a large volume pressure vessel equipped with movable sputtering electrodes. The vessel is loaded, closed, and pumped down to the operating level after which the glass is coated, the vessel vented and reopened, and the coated glass removed. Examples of such facilities are disclosed by U.S. patents 3.907.660; 3,891,536; and 3,738,928.

These approaches attempt to reduce the adverse affects on production rates caused by the long pumping times required to suitably evacuate the vessels. In addition the vessels can be of cylindrical or semi-cylindrical shape which reduces the cost of their construction.

There are some practical drawbacks to these approaches. In addition to the length of time required to simply evacuate these vessels to their operating levels, the vessels are opened to atmosphere between coating operations and a large number of sheets of glass and their supporting structures are placed inside. This further extends the pumping time because substantial numbers of water and oxygen molecules, as well as other contaminants are introduced into and trapped by the vessel walls, the glass itself and its supporting structure. Such contaminants are gradually released and expelled as the pumping chamber pressure is reduced and maintained at a given level.

The higher the chamber pressure remains during coating, the more likely it is that such molecules will be present in significant numbers during coating. Opening the vessel to atmosphere between coating operations and replacing the racks etc. replenishes the supply of these contaminants.

The interior of the chambers thus tends to be "dirty", even at exceedingly low pressures. The presence of these molecules can adversely effect the quality of the final coating. Purging the vessels of such molecules by maintaining the coating pressure level for a period of time before coating the glass is desirable; however, this further extends the cycle time.

Moreover, it is sometimes difficult to assure that the substrates remain clean before and during their assembly into the pressure vessels or on the supporting racks. That is to say, each substrate to be coated can not be cleaned immediately before being placed in the vessel and coated. The longer the substrates are exposed to ambient atmosphere and the more handling they receive the more likely it is that contamination will occur.

Attempts to increase the rate of production of coated glass have resulted in some more or less continuous coating facilities. One such proposal is disclosed by U.S. patent 3,925,182 in which a series of aligned chambers separated by pressure doors is provided and through which the glass is conveyed on suitable supports. The disclosed system employs a coating chamber with entrance and exit chambers on its opposite ends. The chambers are all about the same length and the equipment is designed so that the entrance and coating chambers communicate with each other as the coating process begins and the exit and coating chambers communicate as the coating process ends.

The chambers are mechanically evacuated with the entrance and exit chambers being pressure equalized, respectively, with the coating chamber at different times during each cycle to enable passage of the glass through the apparatus. The pumping time required for operating the equipment through a cycle tends to be reduced by providing minimum volume rectangular cross-section chambers and by operating the system at fairly high coating pressure levels (e.g. in excess of 13,33 Pa); however, the exit and entrance chambers have to be pumped down from atmospheric pressure to the coating pressure level during each cycle. This is relatively time consuming because of the pumping inefficiency not withstanding the relatively small volume chambers.

The operation of this system requires back filling the entrance and exit chambers with inert gas in order to better assure a "clean" atmosphere in the coating chamber when it communicated with the entrance and exit chambers. Nevertheless contaminants can continue to be problems both of the relatively high coating pressure and because the entrance and exit chambers are opened to atmosphere and to the coating chamber during each cycle, enabling contaminants to enter the chambers with the entrance and exit of each batch of substrates and supports.

Providing additional chambers and/or lengthening the chambers relative to the maximum substrate length tends to increase the cost and complexity of the equipment to the extent that such installations are considered uneconomical. In particular, because the chamber volumes are kept as small as possible to increase the pumping rates, the differential pressure forces tending to crush the chamber walls are extremely great and require expensive pressure wall constructions.

The present invention provides a new and improved method and apparatus for coating large substrates, such as architectural glass lights, wherein the substrates are introduced to and removed from a deep vacuum coating chamber while maintaining extremely low coating chamber pressure levels, contamination of the substrate surfaces and the coating chamber atmosphere is minimized, pumping efficiency is maintained relatively high and capital expenditures required for constructing the equipment are not exceedingly great.

Access and working chambers are provided for receiving the substrates and their supports. The access chamber is configured to conform as closely as practical to the substrate shape and thus has a relatively small volume while the working chamber is constructed to provide a volume which is substantially greater than that of the access chamber and has walls configured to withstand extreme differential pressure forces with maximum efficiency.

Substrates are moved into the access chamber from ambient atmospheric pressure and the access chamber is sealed off from the ambient atmosphere and from the working chamber by pressure gates. The access chamber is mechanically pumped to reduce the access chamber pressure substantially below atmospheric pressure to a "roughing" vacuum level which is greater than the working chamber pressure, yet within the range of efficient mechanical vacuum pump operation.

The chambers are then communicated with each other resulting in the pressures in the chambers equalizing substantially below the roughing vacuum level and well into the efficient operating range of a diffusion type vacuum pump associated with the working chamber. The substrates are then advanced into the working chamber, the chambers are again isolated from each other and the diffusion pump is operated to reduce the chamber pressure. After coating, the substrates are locked out of the working chamber. The pressure in the working chamber, because of the relatively large working chamber volume, is maintained at a low level throughout the operation of the

system.

The large working chamber volume thus aids in increasing the efficiency and speed of the vacuum pumping, and eliminates the need for mechanical pumps to pump out the working chambers during each coating cycle. Moreover the large volume permits stationing multiple electrodes in the working chamber. These additional electrodes can be used serially to provide for reactive sputtering or placing diverse coatings on the same substrate, or can accommodate replacement sputtering electrodes to lengthen the interval between electrode replacements.

According to the invention the working chamber includes a coating chamber section in which the substrates are coated at extremely low pressures in a controlled atmosphere and an isolation chamber section interposed between the coating chamber and an access chamber. The coating and isolation chamber sections are equipped with individual molecular pumping systems. The isolation chamber section, which has a volume larger than three times the access chamber, is normally maintained at a lower pressure than the coating chamber section so that the isolation chamber section not only coacts with the adjacent access chamber in the manner referred to for increasing pumping efficiency and effectiveness but also improves the cleanliness of substrates and their supports entering the coating chamber section because of the extensive degassing which occurs in the isolation chamber section as the pressure is reduced below the coating chamber section pressure level. Perhaps even more importantly the coating chamber section atmosphere is purged each time a substrate is moved between the coating and isolation chamber sections because of the lower pressure established in the isolation chamber section.

The working chamber is constructed in the form of a cylindrical pressure vessel. The cylindrical pressure wall configuration is inherently stronger in resisting differential pressure forces tending to crush the chamber than are rectilinear walls which must be strongly reinforced. The cost of fabrication of the new system is significantly reduced because of the configuration of the working chamber.

The preferred access chamber configuration is formed by a pressure wall structure defining a relatively narrow elongated chamber having a rectangular cross section. This chamber configuration generally conforms to the substrate shape and thus minimizes the pumping volume so that it can be rapidly evacuated by an associated roughing vacuum pump. The access chamber length just exceeds the maximum length substrate the system is designed to accept and is substantially less than the working chamber length so that the magnitudes of differential pressure forces acting on the access chamber walls are minimized.

A transition wall section extends between the working chamber and the access chamber. The transition wall is formed by panels hermetically bonded to a circular working chamber end wall and converging proceeding away from a rectangular opening in the end wall. The transition wall defines a rectangular internal cross-sectional shape which decreases in height and width proceeding toward the access chamber walls to which the panels are also hermetically bonded. A pressure door seats about the working chamber opening and swings open into the enlarged end of the transition wall section to enable pressure communication of the chambers and unencumbered passage of substates past the door.

Thus, the present invention provides a method of depositing material by sputter coating on large size substrates such as architectural glass lights at extremely low pressures, which comprises the steps of:

(a) moving a substrate into an access chamber isolated from an isolation chamber by a pressure gate, and mechanically evacuating said access chamber to a first predetermined roughing vacuum pressure level, which is no less than 66,67 Pa;

(b) communicating said access chamber with said isolation chamber residing at a second vacuum pressure level lower than the first vacuum pressure level, the isolation chamber having a volume no less than three times the volume of said access chamber, to thereby produce an intermediate vacuum pressure level in said communicated access and isolation chambers, which pressure is no more than 26,67 Pa;

(c) advancing the substrate into said isolation chamber, isolating said access and isolation chambers, and evacuating said second chamber by diffusion pumping to said second vacuum pressure level to condition the substrate for coating;

(d) communicating said isolation chamber with a coating chamber isolatable from said isolation chamber by a pressure gate, said coating chamber being maintained before communication at a sputtering pressure which is higher than said second vacuum pressure level and after isolating the coating chamber establishing a chemically controlled atmosphere therein suitable for sputter-coating, the communication between said isolation chamber and said coating chamber including purging said coating chamber atmosphere; and

(e) advancing the substrate into said coating chamber, isolating it and depositing material by sputter-coating on said substrate.

The present invention also provides an apparatus for performing the method mentioned hereinabove, which comprises :

(a) a working chamber comprising a coating chamber section and an isolation chamber section, both defined by a generally cylindrical pres-

sure wall;

(b) an access chamber adjacent said isolation chamber section and formed by a rectangular pressure wall structure extending closely about the substrates to minimize the pumping volume of said access chamber and provided with mechanical roughing vacuum pumping means for evacuating said access chamber to a first, roughing, vacuum pressure level, which is no less than 66,67 Pa;

(c) structure defining pressure gates between said chamber sections, between said access and working chambers and between said access chamber and ambient atmosphere;

(d) said access chamber and said isolation chamber section being constructed so that the internal volume ratio between said isolation chamber section and said access chamber is no less than three to one so that when said access chamber and said isolation chamber section are communicated, pressure equalisation occurs to assure that an intermediate pressure level in the communicated chambers is reached, which pressure is no more than 26,67 Pa, said isolation chamber being provided with first diffusion pumping means for evacuating said isolation chamber section from said intermediate pressure level when the pressure gate separating it from the access chamber is closed;

(e) said coating chamber section is provided with second diffusion pumping means for evacuating it and with a source of gas communicating with it for providing a controlled atmosphere in said coating chamber section.

(f) a conveyor system for supporting and moving substrates through said chambers via said gates.

In an illustrated and preferred embodiment of the invention, a system for sputter coating large substrates on a continuous basis is provided having a working chamber system and entrance and exit access chamber systems. The working chamber system is formed by a central coating chamber section and isolation chamber sections through which substrates are introduced into and removed from the coating chamber section. The isolation chamber sections are independently communicated with the coating chamber via pressure doors between them through which substrates are moved. The isolation chamber sections each coact with their respective adjacent access chambers so that substrates can be moved between an access and isolation chamber while other substrates are being coated. The isolation chamber sections are each operated below the coating chamber section pressure except when communicating with their respective access chambers to reduce the chamber pressures into the diffusion pumping range.

The access chambers are communicable and can also be used to partially evacuate each other to reduce pumping time. When one access chamber is at low vacuum pressure preparatory to being vented to atmosphere and the other is atmospheric pressure preparatory to being evacuated, the chambers are communicated so that the air in the higher pressure chamber expands to the evacuated chamber. The chambers are then isolated from each other again for venting and vacuum pumping, respectively.

Other features and advantages of the invention will become apparent from the following description of a preferred embodiment made with reference to the accompanying drawings which form part of the specification.

Figure 1 is a perspective view of a coating apparatus embodying the invention;

Figure 2 is a cross-sectional view seen approximately from the plane indicated by the line 2-2 of Figure 1;

Figure 3 is a top plan view of part of the apparatus illustrated by Figure 1;

Figure 4 is an elevational view of the part of the apparatus illustrated by Figure 3;

Figure 5 is a top plan view of part of the apparatus illustrated by Figure 1; and

Figure 6 is an elevational view of the part of the apparatus illustrated by Figure 5.

A large scale substrate coating apparatus 10 constructed according to the present invention is illustrated in part by Figure 1 of the drawings. Substrates, in the form of architectural glass lights 12, are attached to supporting racks, or frames, 14 and moved through an evacuated working chamber system 16 where the substrates are coated, preferably by cathodic sputtering. The substrate racks 14 are moved by a conveyor system 18 through the working chamber system 16 via an access chamber system 20, which enables substantially continuous and speedy production of coated substrates.

The operations of the working chamber system 16, the access chamber system 20, the conveyor system 18 and associated components are monitored and governed from a control console, indicated by the reference character 22, which has electrical input signals provided to it from various pressure and position responsive transducer elements on input lines schematically indicated by the reference character 24. Output control signals from the control console are transmitted on output lines schematically illustrated by the reference character 26. The console 22 includes suitable process controlling circuitry (not illustrated) which receives input signals from the various systems of the apparatus and produces appropriate output signals for operating individual components of the system. The console 22 is also preferably equipped with manual overriding devices which enable components of the apparatus to be operated independently of the process control circuitry if desired.

Electrical power for various components of the

apparatus 10, such as the conveyor system 18, vacuum pumps for the chamber systems, and so forth is provided from a power supply indicated by the reference character 27 via suitable overhead conduits, schematically shown.

The access chamber system 20 enables substrates to be introduced into and removed from the apparatus 10 without requiring the working chamber system to be vented to atmospheric air pressure. Referring to Figures 1 and 3-6 the access chamber system 20 comprises entrance and exit chambers 30, 32 respectively, a roughing vacuum pumping unit 34 associated with the chambers, and entrance and exit pressure gates 36, 38 for sealing the chamber interiors from the ambient atmospheric air.

The chambers 30, 32 are each designed to just receive two substrate racks 14 side-by-side (with the glass lights 12 on the racks confronting each other) with minimum clearances between the chamber walls and the racks. The internal chamber volume is thus as small as possible. The chambers 30, 32 are of identical construction and for convenience like parts of the chambers are indicated by corresponding reference characters. The chambers are both formed by rectangular pressure wall plates 40a, 40b, 40c, 40d, which are hermetically joined along adjacent edges to define a narrow vertically oriented chamber volume having a rectangular cross-sectional shape. The chamber is slightly longer than the racks 14 and defines the maximum length of glass light which can be handled by the apparatus 10 (in the illustrated construction about 12 feet).

The chamber walls are reinforced by I beam assemblies 41 spaced apart along the length of the chamber and girding it. The I beams of each assembly are welded to the adjacent wall plates with the adjacent ends of the I beams mitered and welded together. This construction effectively prevents the chamber walls from collapsing under atmospheric pressure forces when the chamber is evacuated.

The ends of the wall plates 40a-40d adjacent the working chamber system form a transition section 42 between the access chamber and the working chamber system. The wall plates diverge at small angles proceeding toward the working chamber system to form what can be described as a frustum of a rectangular pyramid having its base hermetically welded to the working chamber system. The divergent wall plates have reinforcing webs welded to them for structural support while the interior of the transition section is a rectangular passage of increasing area proceeding toward the working chamber.

The gates 36, 38 are identical and like components of each are indicated by corresponding reference characters. Each gate is formed by a pressure door 44 hinged to the entrance chamber wall and a door actuator 46 (Figures 3 and 4). The door 44 is formed by an imperforate rectangular steel plate connected along one side to the adjacent vertical chamber wall by a hinge 48. The door defines a peripheral sealing section which seats against the end of the chamber when the door is closed. The sealing section is preferably formed by a resilient O-ring type seal which is disposed in a peripheral door groove for engaging the end of the chamber and sealing about the substrate receiving opening.

The door hinge 48 includes a pintle 50 fixed to the chamber wall by a knuckle bracket 52 and supporting a bell crank for rotation about the pintle axis. The bell crank is formed by knuckle body 55 carried on the pintle having vertically spaced arms 56 projecting from it and pivotally connected to the door along its vertical midline. The pivot connection between the crank arms 56 and the door allows the door to squarely seat on the chamber when closed. The knuckle body 55 also has an articulating arm 58 projecting from the door for connection with the actuator 46.

The actuator 46 is preferably a pneumatic ram having its cylinder connected to the entrance chamber and its piston rod connected to the articulating arm 58. Each ram is controlled by a pneumatic valve (not illustrated) which is electrically actuated in response to output signals from the control console 22 to open and close the associated access chamber gate 36, 38. Operating pressure for the actuator 46 is provided from a suitable air pressure source which is not illustrated.

Each pressure gate 36, 38 is equipped with a position sensitive switch arrangement (not illustrated) for indicating when the doors are open and closed. The pressure switches are wired to the console 22 so that door position signals are available for enabling or preventing process control decisions. The switches can be of any suitable construction and location.

The roughing vacuum pumping unit 34 functions to evacuate the entrance and exit chambers 30, 32 and comprises a pumping manifold 60 for communicating both the chambers to the inlets of roughing vacuum pumps 62, 64, 66 (Figure 3). The manifold 60 is preferably formed by a pipe carrying a pump isolating valve 67, chamber isolating valves 68 for isolating respective individual access chambers from the remainder of the manifold 60, and vent valves 69 for venting respective ones of the access chambers to atmospheric pressure.

The manifold pipe extends between the entrance and exit chambers along the working chamber system and has branched ends extending into communication with the respective chambers 30, 32. The pump inlets are connected to the manifold 60 via a tee connection and the pump isolating valve 67. The valve 67 can be closed to enable communication between the access chambers without exposure to the roughing vacuum pumps. Each chamber isolating valve 68 is disposed between the respective branched pipe ends and the remainder of the manifold 60

while each vent valve 69 is stationed between the associated isolating valve and the chamber. The use of branched pipe ends maximizes flow area for air pumped from and vented into the respective access chambers. During venting the relatively large flow area provided by the branched pipe ends tends to limit the velocity of the atmospheric air flowing into the chambers. Extreme flow velocities in the confined access chambers might otherwise cause sufficient turbulence to damage the substrates.

The isolating and vent valves are electrically controlled by individual output signals from the control console 22 and can be of any suitable construction. The valves are preferably actuated by air pressure from the same source which operates the pressure gate rams.

The pumps 62, 64, 66 are all electric motor driven reciprocating piston, compressor type pumps which are particularly efficient when pumping gas which is sufficiently dense to exhibit fluid flow characteristics, for example, gas at above absolute pressures of about 66,67 Pa. Operation of the pumps is initiated and terminated in response to output signals from the console 22 via the lines 26. Each pump has its inlet connected directly to the manifold 60.

The preferred pumps are each capable of providing a pumping flow rate of about 0,40 m^3/S with atmospheric pressure at their inlets. The actual pumping flow rate diminishes as the pumps evacuate one or the other of the chambers 30, 32 and when the gas density is reduced to a level where its flow can be characterized as molecular flow, or molecular in nature, (generally below 66,67 Pa), the pumping speed diminishes quite markedly. This occurs because the pump inlets have relatively small areas and the statistical probabilities of gas molecules entering them become quite small as the number of available molecules is decreased.

The use of roughing vacuum pumps which are highly efficient in pumping gas exhibiting fluid flow characteristics is an important consideration because these pumps are relatively inexpensive and enable evacuation of the relatively small volume chambers 30, 32 from atmospheric pressure to the range of 93,33-66,67 Pa with great speed.

It should be appreciated that there may be some reciprocating piston vacuum pumps which, because of design geometry, etc., can operate relatively efficiently down to about 40,00 Pa. Other pumps, such as axial flow turbine pumps, could also be employed in place of the pumps 62, 64, 66, but such pumps are extremely expensive particularly in the sizes required to duplicate the capacity and effective pressure range of the illustrated pumps associated with the apparatus 10. However the use of these kinds of pumps in an apparatus constructed according to the present invention is not particularly advantageous because their high degree of performance below 66,67 Pa would not normally be required.

The access chamber system 20 is provided with suitable pressure transducers (not illustrated) which respond respectively to the entrance and exit chamber pressures for enabling control of operation of the apparatus 10 from the control console 22. The pressure transducers produce output signals when the respective access chambers are at atmospheric pressure and at a desired roughing vacuum level (93,33 Pa). The transducer output signals are fed to the control console 22 via the line 24 for use in controlling operation of the roughing vacuum pumps, the various isolation valves, the conveyor system and pressure gates associated with the access chambers.

The working chamber system comprises a central coating chamber section 70 and isolation chamber sections 72, 74 each interposed between an end of the coating chamber and a respective access chamber. Substrates are conveyed successively through the isolation chamber 72, the coating chamber 70 and the isolation chamber 74 during the coating operation. The coating and isolation chambers are formed by a succession of flanged cylindrical pressure wall sections hermetically welded together at their end flanges. Opposite ends of the working chamber system are each formed by a circular end plate 76 hermetically welded about its periphery to the adjacent pressure wall section. Substrate racks move between the access chamber system and the isolation chambers via rectangular openings formed in the end plates 76 which conform to and are aligned with the adjacent access chamber. The ends of the access chamber transition sections 42 are welded to the end plates, 76 about the opening and the transition wall reinforcing webs are also welded to the end plates.

Pressure gates open and close communication between each isolation chamber and the respective associated access chamber. The pressure gates are of identical construction and like components are indicated by corresponding reference characters. Each gate includes a pressure door 84 hinged to the end plate 76 for opening into the transition section 42 (illustrated by broken lines in Figures 3 and 5) and a door actuator 86. Operation of the actuator 86 to open and close the pressure door is governed by output signals from the console 22 via the line 26.

The pressure door 84 and its hinge are constructed generally like the pressure door 44 and the hinge 48 and therefore are not described in detail except where the constructions are slightly different. The actuator 86 is supported atop the isolation chamber pressure wall and is formed by a pneumatic ram, like the actuator 46. The ram operates the door 84 via a shaft 88 extending downwardly on the door hinge axis from the actuator through a seal assembly mounted on the transition section wall. The shaft 88 forms the hinge pintle and is drivingly connected to the pressure

door. The reception of the open pressure door 84 in the transition section 42 assures adequate clearance for the racks to pass the door, as noted, while minimizing the volume of the access chamber and the transition section to assure quick pumping of the access chamber system.

The access-isolation chamber gates are equipped with position sensitive switch arrangements for indicating when the gates are fully opened and closed. The switches (not shown) are connected to the console 22 via the lines 26 to produce signals for enabling or preventing movement of substrates in the apparatus pump operation, and so forth. The switches can be of any suitable construction and positioned, for example, adjacent movable parts of the door actuator 86.

The substrate racks 14 are moved into and through the apparatus 10 by the conveyor system 18 which is schematically illustrated and can be of any suitable construction. In the preferred embodiment of the invention the conveyor system is formed by independently operating aligned conveyor sections 18a-18e, each conveyor section disposed within a respective chamber. Each conveyor section is formed by a series of rack supporting rolls mounted for rotation in a frame extending along the bottom of the associated chamber. A variable speed reversible electric motor (not illustrated) drives rolls of each conveyor section by way of a drive shaft extending to the conveyor section through a seal supported in the chamber wall and drive transmitting chains extending between the shaft and driven conveyor rolls. The electric motors are individually controlled by output signals from the console 22 via the lines 26, with operating power being supplied from the power supply 27.

Adjacent ends of the conveyor sections are spaced apart to permit clearance for opening the pressure doors between the chambers. The racks 14 are sufficiently long and rigid to enable them to bridge the spaces between the conveyor sections moving from one chamber to another.

Each conveyor section is provided with position responsive transducers, preferably electric switch assemblies (not illustrated), which detect the presence and absence of substrate racks at predetermined locations along the conveyor section. The switch assemblies are electrically connected to the control console 22 via the lines 24 for enabling control of appropriate conveyor motors, pumps, etc., in accordance with signals provided by the position switches.

The isolation chambers function to: Enable substrate supporting racks to be admitted to and removed from the working chamber system while substrates on other racks are being coated; increase the effective pumping speed and efficiency of the apparatus 10 without requiring use of extremely expensive pumps; and, enhance the quality of coated substrates by effectively purging the coating chamber atmosphere of possible contaminants. In addition the isolation chamber from which substrates are introduced to the coating chamber is effective to reduce the amount of contaminants which could otherwise be introduced to the coating chamber with the substrates and racks to be coated. The isolation chambers are of identical construction and therefore only the isolation chamber 72 between the entrance chamber and the coating chamber is described in detail.

The isolation chamber 72 is defined by a pair of joined cylindrical pressure wall sections, closed at one end by the plate 76 and at the other end by a bulkhead 90 and an associated vacuum pumping system. A pressure gate 92 (see Figure 1) associated with the bulkhead 90 enables substrate supporting racks 14 to move through the bulkhead 90 between the isolation chamber and the coating chamber as well as to communicate the chamber atmospheres. Substrate racks are moved through the isolation chamber 72 on the conveyor section 18b which is aligned with the conveyor section 18a in the entrance chamber.

The isolation and entrance chambers are constructed and arranged so that, when racks are to be transferred to the isolation chamber from the entrance chamber the vacuum pumps associated with the chambers need not be operated in the transition pressure range between fluid and molecular flow. The isolation chamber volume is large compared to the access chamber volume, with the cylindrical pressure wall having about a 3,05 m diameter and a length of about 4,88 m. The volume ratio of the access chamber to that of the isolation chamber is, in the preferred embodiment of the invention, approximately 1:4. When the isolation chamber is at a lower pressure than the entrance chamber and the pressure door 84 is opened, the atmosphere in the access chamber expands into the isolation chamber and pressure equalization occurs with the final pressure being relatively nearer the original isolation chamber pressure than the original access chamber pressure.

A molecular flow vacuum pumping system 100 (Figures 1 and 3) is associated with the isolation chamber for quickly evacuating the isolation chamber to extremely low pressures, i.e., absolute pressures of between 1,33 mPa and 0,13 mPa. In the preferred and illustrated embodiment the pumping system 100 includes a suitable or conventional oil diffusion pump 102 and the usual associated mechanical pumps 104 for pumping the discharge gas from the diffusion pump. The preferred oil diffusion pump 102 is rated as a 889 or 914 mm pump in that the pump intake has a 889 or 914 mm diameter. The ability of a molecular flow pump to remove gas from an evacuated space is directly related to the area of the pump intake and accordingly the large intake opening of the pump 102 enables relatively fast and effective pumping of gas molecules from the isolation chamber. The isolation chamber wall has pump intake ducting structure 106

formed integrally with it and the pumping system 100 is attached to a suitable mounting flange on the ducting structure 106.

Operation of the pumping section 100 is initiated and terminated by control signals from the console 22 via the lines 26 while power for operating the pumping system is provided from the power supply 27.

The pressure gate 92 is formed by a pressure door 110 connected to the bulkhead 90 by a hinge structure and driven between its open and closed position by an actuator 114 (figure 3) attached to the exterior of the working chamber. The actuator 114 is operated in response to control signals provided from the console 22 via the lines 26. The pressure door, hinge and actuator are constructed substantially the same as the previously described pressure gates between the access and isolation chambers.

The isolation chamber 74 is essentially a mirror image of the isolation chamber 72 and all of the chamber components are identical to those of the chamber 72 except where otherwise indicated. Accordingly the construction of the components of the chamber 74 are not described in detail and are indicated by the same reference characters used in conjunction with identical components of the chamber 72.

Both isolation chambers are provided with suitable pressure transducers (not illustrated) for producing electrical output signals which are fed to and monitored by the control console 22 so that movement of substrates to and from the isolation chambers, operation of the pumping systems, etc., is enable or prevented in response to sensed chamber pressures. Similarly, the pressure gates 92 are equipped with door position sensing switch arrangements connected to the console 22 for indicating whether the doors are open or closed so that movement of substrates and operation of pumps can be governed accordingly.

The isolation chamber 72 differs from the isolation chamber 74 in that a heater 118 is disposed in the chamber 72 between the paths of travel of the substrates for further facilitating conditioning of the substrates for coating. The heater 118 heats the substrates and racks to aid in driving moisture retained on them into the isolation chamber atmosphere by evaporation. It should be noted that a considerable amount of moisture can be retained by the substrates and racks through the period of the access chamber evacuation and heating the substrates and racks in the isolation chamber 72 provides an important supplemental conditioning effect. The heater 118 is preferably a radiant heater producing radiation whose frequency is tuned for absorption by the substrates and racks. A glow discharge type heater could alternatively be employed if desired. The heater 118 is suspended in the chamber 72 from a top access port and electrically connected to the power supply 27.

The coating chamber 70 is defined within the cylindrical pressure walls between the bulkheads 90 and, in the illustrated embodiment of the invention, is equipped to coat substrates moving through it utilizing D.C. sputtering techniques at deep vacuum pressures in an inert, or at least chemically controlled, atmosphere. The preferred coating chamber is at least slightly greater than twice the length of the substrate racks 14 to enable the racks and substrates to be stationed entirely within the coating chamber with the gates 92 closed both before and after coating takes place. In other words, the coating chamber is of sufficient length that substrate coating takes place when both of the gates 92 are closed.

The coating chamber is evacuated by a molecular flow vacuum pumping system formed by a pair of molecular flow vacuum pumps 120 which are operated together to maintain an absolute coating chamber pressure level in the range of 0,27-6,67 Pa during the coating process. Each illustrated pump 120 is a 508 mm oil diffusion pump mounted to an intake duct 122 and provided with a mechanical exhaust pump unit 124. The intake ducts are located adjacent opposite ends of the coating chamber so that the gas molecules tend to drift generally away from the central part of the coating chamber where the coating process takes place. Operation of the pumps 120 is controlled by output signals from the console 22 via the lines 26.

In the preferred apparatus 10 the central section of the coating chamber is provided with a series of spaced access ports 126 arrayed along the top of the chamber and aligned in the plane of the central axis of the chamber. Each port 126 is surrounded by a mounting flange to which a sputtering electrode assembly 128 can be mounted and sealed in place (see Figure 2). The ports 126 are positioned so that a sputtering electrode of each electrode assembly extends downwardly within the coating chamber and between the substrate supporting racks. In the illustrated embodiment of the invention two electrode assemblies are mounted and sealed in place in separate ones of the ports 126, the remaining ports being sealed closed by suitable covers removably attached to the respective port flanges. Each electrode assembly includes a single depending cathode electrode 130 (see Figure 2) capable of simultaneously sputtering material onto substrates as they move past on opposite sides of the electrode.

Each electrode 130 is electrically connected to a respective D.C. power supply which can be of any suitable construction and is illustrated as enclosed within a housing 132 (Figure 2). Coolant, preferably water, is fed to the assembly via dielectric tubes. The power and coolant are provided to the electrode 130 via an electrode supporting plate 134 sealed in place across a respective chamber port.

The electrode assemblies referred to are preferably identical to enable substrates to be coated from one electrode and then, when its supply of sputtering material is exhausted, from the other electrode. Pro-

viding multiple identical electrodes lengthens the time between electrode assembly replacement. Electrode replacement requires venting the apparatus to atmosphere which is undesirable because of the lost production time. The illustrated coating chamber has five access ports, each capable of receiving an electrode assembly.

As indicated previously the sputtering takes place in a controlled atmosphere. As illustrated by Figure 1 a source 140 of Argon gas in the form of a tank, or tanks, of compressed Argon is communicated to the working chamber via a supply line 142 and control valve 144. The gas is admitted to the coating chamber through vertically spaced nozzles supported in the control part of the coating chamber in alignment with the electrodes. The nozzles direct the Argon toward the electrodes between the substrate racks so that a supply of ionizing gas adjacent the electrodes is assured. The flow rate of Argon into the coating chamber is restricted by the control valve 144 and the nozzles and is adjusted so that the coating chamber pressure is readily maintainable between 0,27 and 6,67 Pa with the pumps 120 operating during the coating process.

The preferred sputtering electrode assembly and associated equipment is described in greater detail in the cross referenced application of Chambers and Wan, the disclosure of which is incorporated herein in its entirety by this reference to it. The operation of this equipment is governed by control signals produced by the console 22 via the lines 26.

The coating chamber is provided with a pressure transducer (not shown) for transmitting pressure level indicative signals to the console 22. The console 22 monitors the coating chamber pressure to enable the chamber atmosphere pressure to be stabilized at the desired coating pressure level.

The apparatus 10 is prepared for operation by installing appropriate electrode assemblies in the coating chamber, connecting them to their power and coolant supplies, connecting the Argon source to the chamber and evacuating the working and isolation chambers down to their operating pressures. Because diffusion pumps are ineffective for evacuating a chamber having an internal pressure greater than about 26,67 Pa, the apparatus 10 must be pumped down to the diffusion pump operating pressure range by the roughing vacuum pumping system. Accordingly, the gates 36, 38 are closed, the remaining internal pressure gates are opened, the isolating valves 67, 68 are opened and the roughing vacuum pumps are operated to evacuate the working chamber system.

The chambers are evacuated to about a 66,67 Pa pressure level fairly quickly; but the roughing vacuum pumps rapidly lose efficiency when the intake gas loses its fluid flow characteristics and begins to exhibit molecular flow characteristics. This transition begins at chamber pressures around 66,67 Pa. Nevertheless the roughing vacuum pumps continue to operate until the chamber pressure is reduced to 20,00-26,67 Pa. This requires considerable time because of the relatively small roughing vacuum pump inlet openings, as noted previously.

When the chamber system pressure is reduced sufficiently to enable diffusion pump operation the doors 84 are closed to isolate the access chambers from the working chamber system and all of the diffusion pumps are energized. At the same time the isolation valves 67 and 68 are closed to isolate the entrance and exit chambers from each other and from the roughing vacuum pumping system. The diffusion pumps reduce the system pressure to just a few tenths of Pascal relatively quickly.

The pumping speed of the diffusion pumps is affected to some extent by how "dirty" the working chamber system is inside. Whenever the working chamber system is opened and exposed to atmospheric air, contaminants are introduced to the chambers. For example, it is inevitable that water vapor and molecules of gases from the air are trapped by the chamber walls. Organic substances can likewise be introduced in any one of a number of ways. If the working chamber system is relatively "dirty" the time required to reduce the pressure is lengthened because of the numbers of contaminant molecules which must be "degassed" from the chamber. When the working chamber system contaminants have been substantially degassed, the working chamber pressure falls into the range of 1,33 mPa to 0,13 mPa primarily under control of the diffusion pumps 102.

The amount of time taken to evacuate the apparatus varies, as noted, but the reduction of pressure through the roughing vacuum range (to about 26,67 Pa usually requires about 45 minutes. If the chambers are clean (for example, if the apparatus 10 has only been opened to atmosphere to change electrode assemblies) the pumping can be completed in about one hour. If the apparatus been fully opened to atmosphere with work of one kind or another conducted in the chambers the pumping time can be extended materially.

After the initial pump-down is completed the coating chamber atmosphere and operating pressure level are established. To accomplish this the gates 92 are closed to isolate the coating chamber and the Argon source control valve 144 is opened to introduce Argon into the coating chamber. The coating chamber is provided with a sufficient Argon flow to establish an atmosphere having a pressure of between 3,33 and 6,67 Pa with both diffusion pumps 120 operating. This pressure is maintained by operating the diffusion pumps continuously while Argon is being supplied.

In accordance with an important feature of the invention the apparatus 10 is so constructed and arranged that, after the initial pump down, the system is operated without requiring either the roughing va-

cuum pumps or the system diffusion pumps to be operated in the flow transition region between 66,67 and 26,67 Pa. The preferred system is constructed and operated so that the roughing vacuum pumps operate down to between 93,33 and 66,67 Pa and the diffusion pumps operate primarily below about 20,00 Pa. This optimizes pumping efficiencies, minimizes the time required for moving substrates through the apparatus, and obviates the need for additional, highly expensive vacuum pumps capable of operating in the flow transition region.

Substrates to be coated are introduced by opening the entrance chamber vent valve 69 and, when the entrance chamber 30 is vented to atmospheric pressure, opening the pressure door 44 for reception of substrate supporting racks. A pair of the substrate supporting racks 14 is guided onto the entrance chamber conveyor section 18a and advanced until the racks actuate the position responsive switches indicating that the racks are completely within the entrance chamber. The switch actuation results in stopping the conveyor section 18a and closing the pressure door 44.

The access chamber is then reevacuated. Upon closure of the door 44 the pump isolating valve 67 is closed and the isolation valves 68 are opened to communicate the entrance and exit chambers. Since the exit chamber 32 had remained at a pressure of about 26,67 Pa the entrance chamber atmosphere expands into the exit chamber reducing the total access chamber system pressure to about one half atmospheric pressure. The isolation valve 67 is then opened, the exit chamber isolation valve 68 is closed and the roughing vacuum pumping system is operated to continue evacuation of the entrance chamber. The entrance chamber is pumped until its internal pressure is between 93,33 and 66,67 Pa, absolute pressure, at which time the entrance chamber pressure transducer produces an output signal effective to reclose the entrance chamber isolation valve 68. Evacuating the entrance chamber to 93,33-66,67 Pa occurs quite quickly both because the reciprocating piston roughing pumps are operated efficiently in the fluid flow pressure range and because the entrance chamber configuration minimizes the pumping volume. In the preferred system pumping the entrance chamber is pumped to the roughing vacuum level from about one half atmospheric pressure in approximately 80 seconds.

At this juncture the entrance chamber isolation valve 68 is reclosed and the exit chamber isolation valve 68 is opened. The roughing vacuum pumps continue to operate until the exit chamber has been pumped down to the roughing vacuum level again.

After the entrance chamber isolating valve 68 is closed the pressure door 84 between the entrance and isolation chambers is opened. The isolation chamber is substantially larger than the access chamber so that the gas in the access chamber expands into the isolation chamber. The resultant pressure in the chambers is substantially lower than the access chamber roughing vacuum level and well within the effective pumping pressure range of the isolation chamber diffusion pump, i.e., approximately 20,00 Pa. The preferred isolation chamber is configured wtih a volume at least 3.5 times the volume of the access chamber to insure optimum expansion of the access chamber atmosphere.

When the pressure door 84 is opened the conveyor sections 18a, 18b in the entrance and entrance isolation chambers are operated to advance the substrate supporting racks into the isolation chamber 72. The rack advancement is terminated when the racks encounter the limit switches in the isolation chamber. Operation of the switches enables deactivation of the conveyor sections 18a, 18b, closure of the pressure door 84.

The diffusion pump 102 quickly reduces the pressure in the isolation chamber to 1,33 mPa or less which results in the racks and substrates being subject to degassing of contaminants throughout the period of their residence in the isolation chamber. The pump 102 can usually reduce the isolation chamber pressure to less than 1,33 mPa in about 10 seconds although a somewhat longer period is required if the racks and/or substrates are abnormally "dirty". No specific chemical atmosphere need be established or maintained in the isolation chamber preparatory to the substrates being advanced from it. In the preferred apparatus the diffusion pump 102 and heater 118 operate continuously.

When the isolation chamber pressure has been reduced appropriately the pressure transducer signal to the console 22 is such that the actuator for the coating chamber pressure door is enabled to operate. If the coating chamber is ready to receive the substrates the pressure door 110 opens to enable the substrate racks to move into the coating chamber.

Meanwhile, the entrance chamber 30 has been vented, a succeeding pair of substrate racks advanced into it and the chamber reevacuated in the manner set forth previously.

The isolation chamber 72 functions to purge the coating chamber as the substrate racks are advanced for coating. As noted, the coating chamber is provided with an Argon atmosphere maintained at an absolute pressure between 3,33 and 6,67 Pa. When the door 110 is opened the coating chamber is fully communicated with the isolation chamber 72 whose pressure is no more than about 1,33 mPa. The atmosphere in the coating chamber is, in effect, cleaned, or purged because the coating chamber atmosphere tends to expand into the isolation chamber when the pressure door between them is opened. The effect of this is that the coating chamber atmosphere, including any impurities, is partially drawn from the coating cham-

ber and the possibility of contaminant molecules entering the coating chamber from the isolation chamber is minimized.

The conveyor sections 18b, 18c are enabled to advance the substrate racks from the isolation chamber to the coating chamber in response to the door 110 opening. When the substrate racks have fully entered the coating chamber, position sensing switches are actuated by them to terminate operation of the conveyor sections and enable the pressure door 110 to reclose. It should be appreciated that, because of purging the coating chamber atmosphere while introducing the substrate and racks, virtually the only sources of contaminants in the coating chamber are the substrates and racks themselves. Because the substrates and racks have been conditioned by degassing in the isolation chamber 72 at lower than coating chamber pressures, the tendency for the racks and substrates to degas further in the coating chamber is reduced. Therefore the coating chamber atmosphere tends to remain quite free from contamination.

After closure of the coating chamber pressure door, the Argon admitted to the coating chamber increases the coating chamber pressure until the coating chamber pressure is between 3,33 and 6,67 Pa. The sputtering electrode is then energized from its power supply and the conveyor section 18c is again operated to move the substrate racks past the electrode at a controlled speed. Electrode material is sputtered onto the substrates as they pass the electrode. After the racks have passed the electrode they encounter position sensing switches which terminate operation of the coating chamber conveyor section and deenergize the electrode so that the racks and substrates are stopped beyond the sputtering electrodes in position for removal from the coating chamber.

The coating chamber conveyor section 18c can be reversed so that the substrates can be reconveyed past the sputtering electrodes if desired to provide additional coating material.

When the substrates and racks are removed from the coating chamber the coating chamber atmosphere is purged by the exit isolation chamber 74 which, like the isolation chamber 72, is normally maintained below 1,33 mPa. The pressure door 110 between the isolation chamber 74 and the coating chamber is opened causing the atmosphere in the coating chamber to expand into the isolation chamber 74, tending to sweep the atmosphere from the coating chamber. The coated substrates are then advanced into the isolation chamber 74 and the pressure door 110 reclosed to cut off communication between the coating and isolation chambers.

The exit chamber 32 is then communicated with the isolation chamber 74 by opening the pressure door 84 between them causing the exit chamber atmosphere (maintained at a roughing vacuum level) to expand into the isolation chamber. The pressure in the exit and isolation chambers equalizes at a level within the operating range of the diffusion pump 102. The substrate racks are then moved into the exit chamber and the pressure door 84 is reclosed to enable the isolation chamber 74 to be pumped down again to between 1,33 and 0,13 mPa. This effectively removes contaminants introduced to the isolation chamber 74 from the exit chamber.

Assuming the entrance chamber 30 contains additional racks of uncoated glass at atmospheric pressure, the isolation valves 68 are opened to allow the entrance chamber atmosphere to expand into the exit chamber. The exit chamber isolation valve is reclosed and the exit chamber vent valve 69 is opened to permit the exit chamber to return to atmospheric pressure. The racks and coated substrates are then advanced from the exit chamber and the vent valve 69 is reclosed. The exit chamber isolating valve 68 is reopened and the exit chamber is again ready to be evacuated to the roughing vacuum level.

If desired, the exit chamber 32 can also be partially evacuated by communicating it to the entrance chamber 30 after the additional racks in the entrance chamber have been advanced to the isolation chamber 72. This is accomplished by communicating the entrance and exit chambers via the isolating valves 68 in the manner noted previously.

The coating process is substantially continuous in that as soon as a pair of racks and substrates are received by the isolation chamber 72 preparatory to coating, the entrance chamber 30 is vented to atmosphere reopened, and receives a second pair of substrate racks. The entrance chamber isolation valve 68 is reopened and the roughing vacuum pumping system 20 is operated to reduce the pressure of the entrance chamber to around 93,33 Pa. Movement of the second pair of substrate racks into the isolation chamber 72 can be accomplished as soon as the preceding substrate racks have been moved into the coating chamber.

Generally speaking, the time taken to coat substrates on one pair of substrate racks in the coating chamber 70 is less than the time required to evacuate the access chambers. The coated substrates are thus held in the coating chamber until the next succeeding pair of substrate racks is disposed in the isolation chamber 72 and conditioned for admittance to the coating chamber. This enables both isolation chambers 72, 74 to be communicated to the coating chamber simultaneously, if desired, so that the coating chamber atmosphere is purged from both ends of the coating chamber as the substrate rack pairs are received by and delivered from the coating chamber.

As noted above the sequence of operation of the chambers can be controlled so that the exit and entrance chambers are communicated to partially evacuate one by the other. If this procedure can not be fol-

lowed for one reason or another the time required to pump either chamber from atmospheric pressure to the roughing vacuum level is increased by approximately 10 seconds.

The apparatus 10 is operated continuously until the sputtering material from all electrodes stationed in the coating chamber has been consumed. The operation continues without requiring the operation of the diffusion pumps outside of their operating pressure ranges and without requiring the roughing vacuum pumps to reduce the entrance and exit chamber pressures to less than about 93,33 Pa, except when the system is initially pumped down.

While a single embodiment of the present invention has been illustrated and described to considerable detail, various adaptations, modifications and uses of the invention will occur to those skilled in the art.

Claims

1. A method of depositing material by sputter-coating on large size substrates such as architectural glass lights at extremely low pressures, which comprises the steps of :

   (a) moving a substrate into an access chamber isolated from an isolation chamber by a pressure gate, and mechanically evacuating said access chamber to a first predetermined roughing vacuum pressure level, which is no less than 66,67 Pa;

   (b) communicating said access chamber with said isolation chamber residing at a second vacuum pressure level lower than the first vacuum pressure level, the isolation chamber having a volume no less than three times the volume of said access chamber, to thereby produce an intermediate vacuum pressure level in said communicated access and isolation chambers, which pressure is no more than 26,67 Pa;

   (c) advancing the substrate into said isolation chamber, isolating said access and isolation chambers, and evacuating said second chamber by diffusion pumping to said second vacuum pressure level to condition the substrate for coating;

   (d) communicating said isolation chamber with a coating chamber isolatable from said isolation chamber by a pressure gate, said coating chamber being maintained before communication at a sputtering pressure which is higher than said second vacuum pressure level and after isolating the coating chamber establishing a chemically controlled atmosphere therein suitable for sputter-coating, the communication between said isolation chamber and said coating chamber including purging said coating chamber atmosphere; and

   (e) advancing the substrate into said coating chamber, isolating it and depositing material by sputter-coating on said substrate.

2. The method according to claim 1, characterised in that said first vacuum pressure level is between 93,33 and 66,67 Pa and said intermediate vacuum pressure level is between 20,00 and 26,67 Pa.

3. The method according to any of the preceding claims, characterised in that said coating chamber is maintained at a vacuum pressure level of no more than 6,67 Pa and said isolation chamber is maintained at a vacuum pressure level of no more than 1,33 mPa, when said coating and isolation chambers do not communicate.

4. Apparatus for performing the method according to anyone of the preceding claims, which comprises :

   (a) a working chamber comprising a coating chamber section and an isolation chamber section, both defined by a generally cylindrical pressure wall;

   (b) an access chamber adjacent said isolation chamber section and formed by a rectangular pressure wall structure extending closely about the substrates to minimize the pumping volume of said access chamber and provided with mechanical roughing vacuum pumping means for evacuating said access chamber to a first, roughing, vacuum pressure level, which is no less than 66,67 Pa;

   (c) structure defining pressure gates between said chamber sections, between said access and working chambers and between said access chamber and ambient atmosphere;

   (d) said access chamber and said isolation chamber section being constructed so that the internal volume ratio between said isolation chamber section and said access chamber is no less than three to one so that when said access chamber and said isolation chamber section are communicated, pressure equalisation occurs to assure that an intermediate pressure level in the communicated chambers is reached, which pressure is no more than 26,67 Pa, said isolation chamber being provided with first diffusion pumping means for evacuating said isolation chamber section from said intermediate pressure level when the pressure gate separating it from the access chamber is closed;

   (e) said coating chamber section is provided with second diffusion pumping means for

evacuating it and with a source of gas communicating with it for providing a controlled atmosphere in said coating chamber section.

(f) a conveyor system for supporting and moving substrates through said chambers via said gates.

5. Apparatus according to claim 4, characterised in that said mechanical roughing vacuum pumping means comprise a reciprocating piston vacuum pump and said diffusion pumping means of the isolation chamber is effective to maintain said isolation chamber pressure level below the pressure level in said coating chamber.

6. Apparatus according to claim 4 or 5, characterised in that said coating chamber is greater than twice the length of the substrate supporting racks to enable coating of substrates with the gate between the isolation and coating chambers being closed.

7. Apparatus according to anyone of claims 4 to 6, characterised in that it comprises two access chambers, an inlet and an exit chamber, and two isolation chambers, intermediate between the access chambers and the coating chamber.

8. Apparatus according to claim 7, characterised in that the mechanical pumps of the two access chambers communicate with a manifold including valve means for isolating said inlet and exit chambers individually from said manifold.

Patentansprüche

1. Verfahren zum Ablagern von Material durch Sprühbeschichtung auf großformatigen Substraten, wie Bauglastafeln, bei extrem niedrigen Drücken, welches Verfahren die nachfolgenden Schritte umfaßt:

(a) Bewegen eines Substrates in eine Zugangskammer, die von einer Isolierkammer durch eine Druckschleuse isoliert ist, und mechanisches Evakuieren dieser Zugangskammer auf eine erste vorbestimmte Grobvakuumdruckhöhe, die nicht weniger als 66,67 Pa beträgt;

(b) Inverbindungsetzen dieser Zugangskammer mit der Isolierkammer, die sich auf einer zweiten Vakuumdruckhöhe befindet, welche niedriger als die erste Vakuumdruckhöhe ist, wobei die Isolierkammer ein Volumen hat, das nicht weniger als das Dreifache des Volumens der Zugangskammer beträgt, um dadurch in den in Verbindung stehenden Zugangs- und Isolierkammern eine Vakuum-Zwischendruckhöhe zu erzeugen, die nicht mehr als 26,67 Pa beträgt;

(c) Vorwärtsbewegen des Substrates in die Isolierkammer, Isolieren der Zugangs- und Isolierkammern und Evakuieren der zweiten Kammer durch Diffusionspumpen auf die zweite Vakuumdruckhöhe, um das Substrat für eine Beschichtung zu konditionieren;

(d) Inverbindungsetzen der Isolierkammer mit einer Beschichtungskammer, die von der Isolierkammer durch eine Druckschleuse isolierbar ist, wobei die Beschichtungskammer vor der Verbindung auf einem Sprühdruck gehalten wird, der größer als die zweite Vakuumdruckhöhe ist, und nach dem Isolieren der Beschichtungskammer Erzeugen einer chemisch gesteuerten Atmosphäre in dieser, die sich zum Sprühbeschichten eignet, wobei das Inverbindungsetzen der Isolierkammer und der Beschichtungskammer das Austreiben der Beschichtungskammeratmosphäre umfaßt; und

(e) Vorwärtsbewegen des Substrates in die Beschichtungskammer, Isolieren derselben und Ablagern des Materials auf das Substrat durch Sprühbeschichten.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die erste Vakuumdruckhöhe zwischen 93,33 und 66,67 Pa und die Vakuum-Zwischendruckhöhe zwischen 20,00 und 26,67 Pa beträgt.

3. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Beschichtungskammer auf einer Vakuumdruckhöhe von nicht mehr als 6,67 Pa und die Isolierkammer auf einer Vakuumdruckhöhe von nicht mehr als 1,33 mPa gehalten wird, wenn die Beschichtungskammer und die Isolierkammer nicht miteinander in Verbindung stehen.

4. Vorrichtung zum Durchführen des Verfahrens nach einem der vorhergehenden Ansprüche, umfassend:

(a) eine Arbeitskammer, die einen Beschichtungskammerabschnitt und einen Isolierkammerabschnitt aufweist, die beide durch eine allgemein zylindrische Druckwandung definiert sind;

(b) eine dem Isolierkammerabschnitt benachbarte Zugangskammer, die durch einen rechteckigen Druckwandaufbau gebildet ist, welcher sich eng um die Substrate erstreckt, um das Pumpvolumen der Zugangskammer zu minimieren, und mit mechanischen Grobvakuumpumpmitteln zum Evakuieren der Zugangskammer auf eine erste Grobvakuum-

druckhöhe ausgestattet ist, die nicht weniger als 66,67 Pa beträgt;

(c) einen Aufbau, der Druckschleusen zwischen den genannten Kammerabschnitten, zwischen der Zugangskammer und der Arbeitskammer sowie zwischen der Zugangskammer und der umgebenden Atmosphäre definiert;

(d) wobei die Zugangskammer und die Isolierkammer so ausgebildet sind, daß das innere Volumsverhältnis zwischen dem Isolierkammerabschnitt und der Zugangskammer nicht weniger als 3:1 beträgt, so daß beim Inverbindungsetzen der Zugangskammer und des Isolierkammerabschnittes ein Druckausgleich stattfindet, um sicherzustellen, daß eine Zwischendruckhöhe in den miteinander in Verbindung gesetzten Kammern erreicht wird, welcher Druck nicht mehr als 26,67 Pa beträgt, wobei die Isolierkammer mit ersten Diffusionspumpenmitteln zum Evakuieren des Isolierkammerabschnittes von der Zwischendruckhöhe versehen ist, wenn die sie von der Zugangskammer trennende Druckschleuse geschlossen ist;

(e) der Beschichtungskammerabschnitt mit zweiten Diffusionspumpemitteln zum Evakuieren desselben und mit einer Gasquelle versehen ist, die mit ihm in Verbindung steht, um im Beschichtungskammerabschnitt eine gesteuerte Atmosphäre zu erzeugen;

(f) ein Fördersystem zum Abstützen von Substraten und zum Bewegen derselben durch die Kammern über die Schleusen.

5. Vorrichtung nach Anspruch 4, dadurch gekennzeichnet, daß die mechanischen Grobvakuumpumpmittel eine Vakuumpumpe mit hin- und hergehendem Kolben aufweisen und die Diffusionspumpmittel der Isolierkammer wirksam sind, um die Isolierkammerdruckhöhe unterhalb der Druckhöhe im Beschichtungskammerabschnitt zu halten.

6. Vorrichtung nach Anspruch 4 oder 5, dadurch gekennzeichnet, daß die Beschichtungskammer größer als die doppelte Länge der Substrattraggestelle ist, um eine Beschichtung der Substrate bei geschlossener Schleuse zwischen der Isolierkammer und der Beschichtungskammer zu ermöglichen.

7. Vorrichtung nach einem der Ansprüche 4 bis 6, dadurch gekennzeichnet, daß sie zwei Zugangskammern aufweist, eine Einlaß- und eine Auslaßkammer, und zwei Isolierkammern, die zwischen den Einlaßkammern und der Beschichtungskammer liegen.

8. Vorrichtung nach Anspruch 7, dadurch gekennzeichnet, daß die mechanischen Pumpen der beiden Zugangskammern mit einem Verteiler in Verbindung stehen, der Ventilmittel zum individuellen Isolieren der Einlaß- und Ausgangskammern vom Verteiler aufweist.

Revendications

1. Procédé pour déposer de la matière par pulvérisation sur des substrats de grandes dimensions tels que des vitrages en verre architectural, à des pressions extrêmement basses, suivant lequel :

(a) on introduit un substrat dans une chambre d'accès isolée d'une chambre d'isolement par une porte étanche à la pression et on fait le vide mécaniquement dans la chambre d'accès jusqu'à un premier niveau de vide grossier prédéterminé qui n'est pas inférieur à 66,67 Pa;

(b) on met en communication la chambre d'accès avec la chambre d'isolement qui se trouve à un deuxième niveau de vide inférieur au premier, la chambre d'isolement ayant un volume qui n'est pas inférieur au triple du volume de la chambre d'accès afin de produire ainsi un niveau de vide intermédiaire dans les chambres d'accès et d'isolement en communication, ce vide n'étant pas supérieur à 26,67 Pa;

(c) on fait avancer le substrat dans la chambre d'isolement, on isole la chambre d'accès et la chambre d'isolement et on fait le vide dans la seconde chambre par un pompage par diffusion jusqu'au deuxième niveau de vide afin de préparer le substrat pour le revêtement;

(d) on met en communication la chambre d'isolement avec une chambre de revêtement pouvant être isolée de la chambre d'isolement par une porte étanche à la pression, la chambre d'isolement étant maintenue, avant la mise en communication, à une pression de pulvérisation qui est supérieure au second niveau de vide et, après avoir isolé la chambre de revêtement, on y établit une atmosphère réglée chimiquement, convenant pour le revêtement par pulvérisation, la communication entre la chambre d'isolement et la chambre de revêtement impliquant la purge de l'atmosphère de la chambre de revêtement;

(e) on fait avancer le substrat dans la chambre de revêtement, on l'isole et on dépose de la matière par revêtement par pulvérisation sur le substrat.

2. Procédé suivant la revendication 1, caractérisé en ce que le premier niveau de vide est compris entre 93,33 et 66,67 Pa et le niveau de vide inter-

médiaire est compris entre 20,00 et 26,67 Pa.

3. Procédé suivant l'une quelconque des revendications précédentes, caractérisé en ce que la chambre de revêtement est maintenue à un niveau de vide ne dépassant pas 6,67 Pa et la chambre d'isolement est maintenue à un niveau de vide ne dépassant pas 1,33 mPa, lorsque les chambres de revêtement et d'isolement ne sont pas en communication.

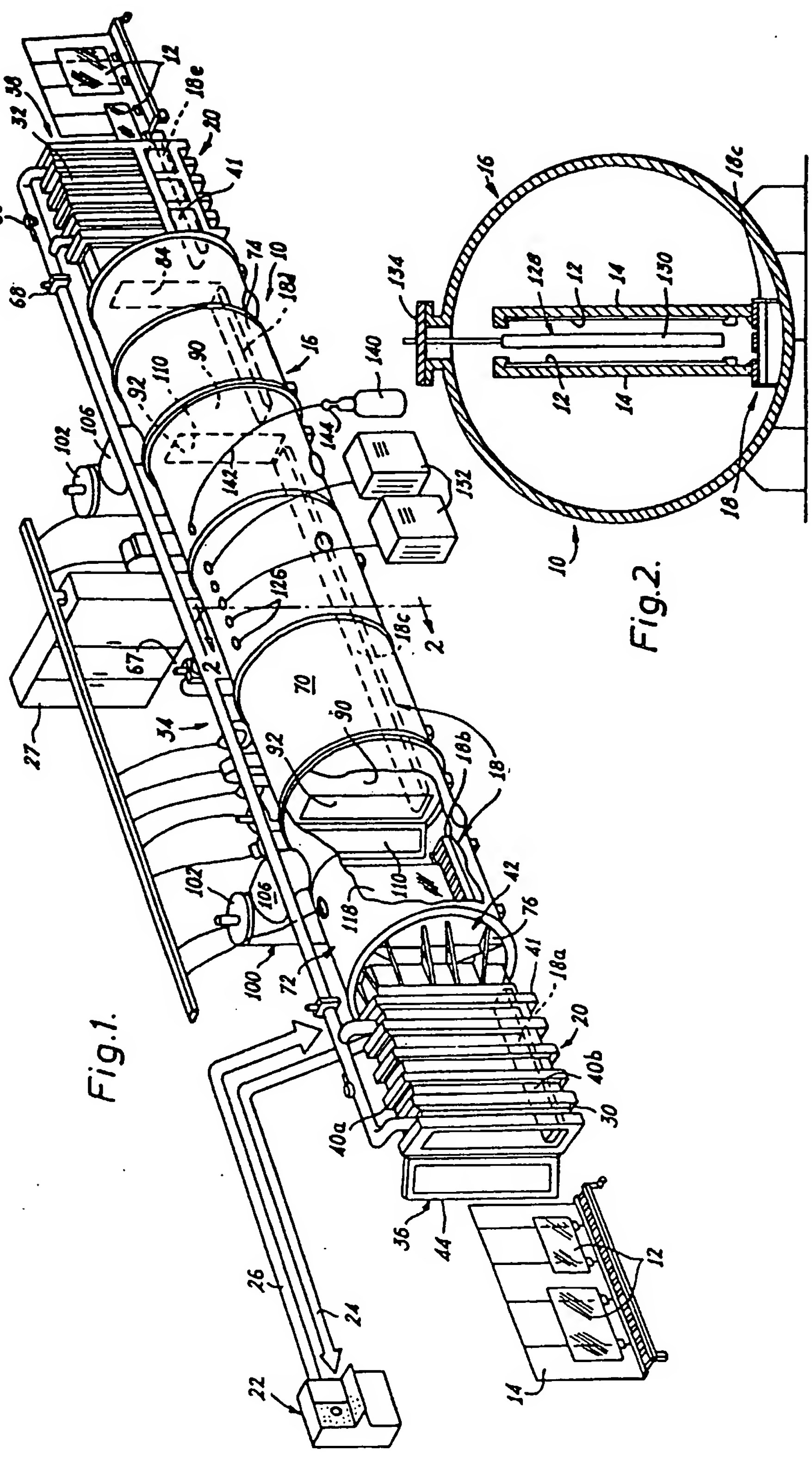
4. Appareil pour exécuter le procédé suivant l'une quelconque des revendications précédentes, qui comprend :
   (a) une chambre de travail comprenant une section de chambre de revêtement et une section de chambre d'isolement toutes deux définies par une paroi à pression généralement cylindrique;
   (b) une chambre d'accès adjacente à la section de chambre d'isolement et formée par une structure de paroi à pression rectangulaire s'étendant à proximité immédiate des substrats et autour de ceux-ci pour réduire au minimum le volume de pompage de la chambre d'accès et pourvue d'un dispositif de pompage à vide grossier mécanique pour faire le vide dans la chambre d'accès jusqu'à un premier niveau de vide grossier qui n'est pas inférieur à 66,67 Pa;
   (c) une structure définissant des portes étanches à la pression entre les sections de chambre d'accès et de travail et entre la chambre d'accès et l'atmosphère ambiante;
   (d) la chambre d'accès et la section de chambre d'isolement étant construites de telle façon que le rapport volumique interne entre la section de chambre d'isolement et la chambre d'accès ne soit pas inférieur à 3:1 de sorte que, lorsque la chambre d'accès et la section de chambre d'isolement sont mises en communication, une égalisation des pressions se produit pour assurer qu'un niveau de pression intermédiaire soit atteint dans les chambres mises en communication, cette pression n'étant pas supérieure à 26,67 Pa, la chambre d'isolement étant pourvue d'un premier dispositif de pompage à diffusion pour faire le vide dans la section de chambre d'isolement à partir du niveau de vide intermédiaire lorsque la porte étanche à la pression qui la sépare de la chambre d'accès est fermée;
   (e) la section de chambre de revêtement est pourvue d'un second dispositif de pompage à diffusion pour faire le vide dans cette chambre et d'une source de gaz communiquant avec cette section pour établir une atmosphère réglée dans la section de chambre de revêtement;
   (f) un système de transporteur pour supporter et déplacer des substrats à travers les chambres via les portes.

5. Appareil suivant la revendication 4, caractérisé en ce que le dispositif de pompage à vide grossier comprend une pompe à vide à piston à mouvement alternatif et le dispositif de pompage à diffusion de la chambre d'isolement est à même de maintenir le niveau de vide de la chambre d'isolement en dessous du niveau de vide de la chambre de revêtement.

6. Appareil suivant la revendication 4 ou 5, caractérisé en ce que la chambre de revêtement a une longueur supérieure au double de la longueur des râteliers de support des substrats afin de permettre le revêtement de substrats lorsque la porte entre la chambre d'isolement et la chambre de revêtement est fermée.

7. Appareil suivant l'une quelconque des revendications 4 à 6, caractérisé en ce qu'il comprend deux chambres d'accès, une chambre d'entrée et une chambre de sortie, et deux chambres d'isolement, entre les chambres d'accès et la chambre de revêtement.

8. Appareil suivant la revendication 7, caractérisé en ce que les pompes mécaniques des deux chambres d'accès communiquent avec une canalisation comprenant des valves destinées à isoler les chambres d'entrée et de sortie individuellement de la canalisation.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132
126
18c
2
67
70
34
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18b
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41
18a
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Fig.1.

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Fig.2.

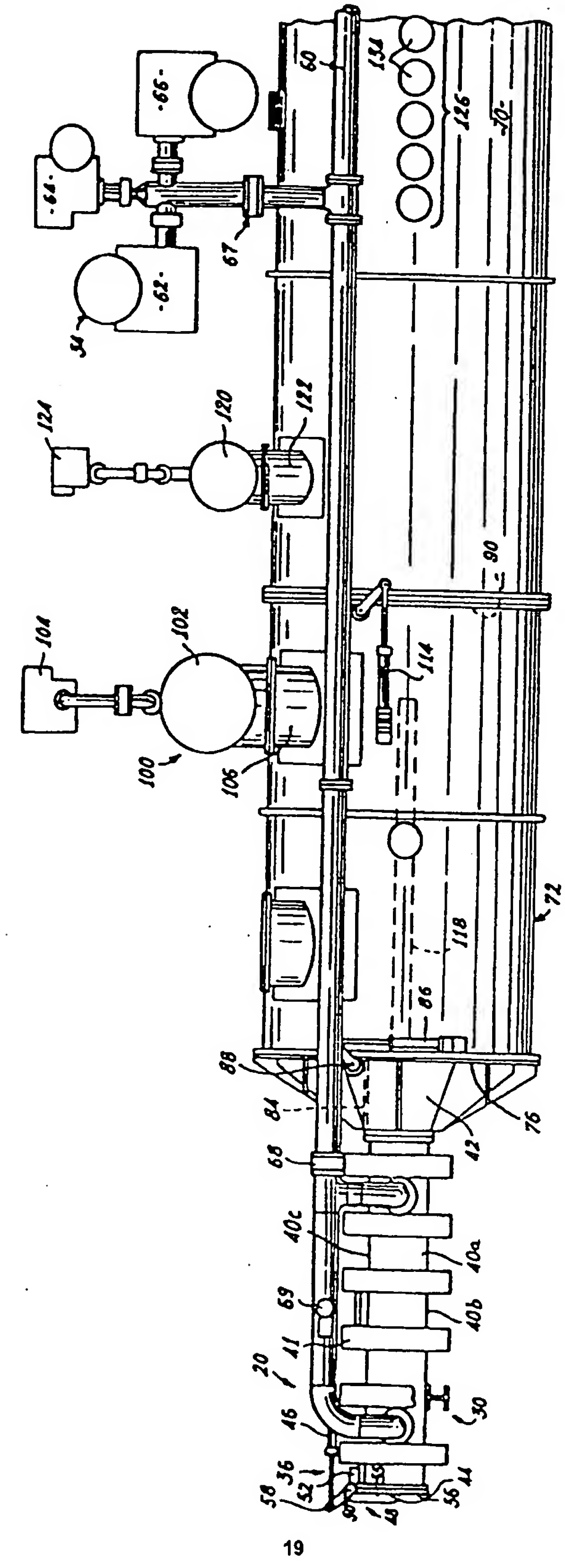
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Fig.3.

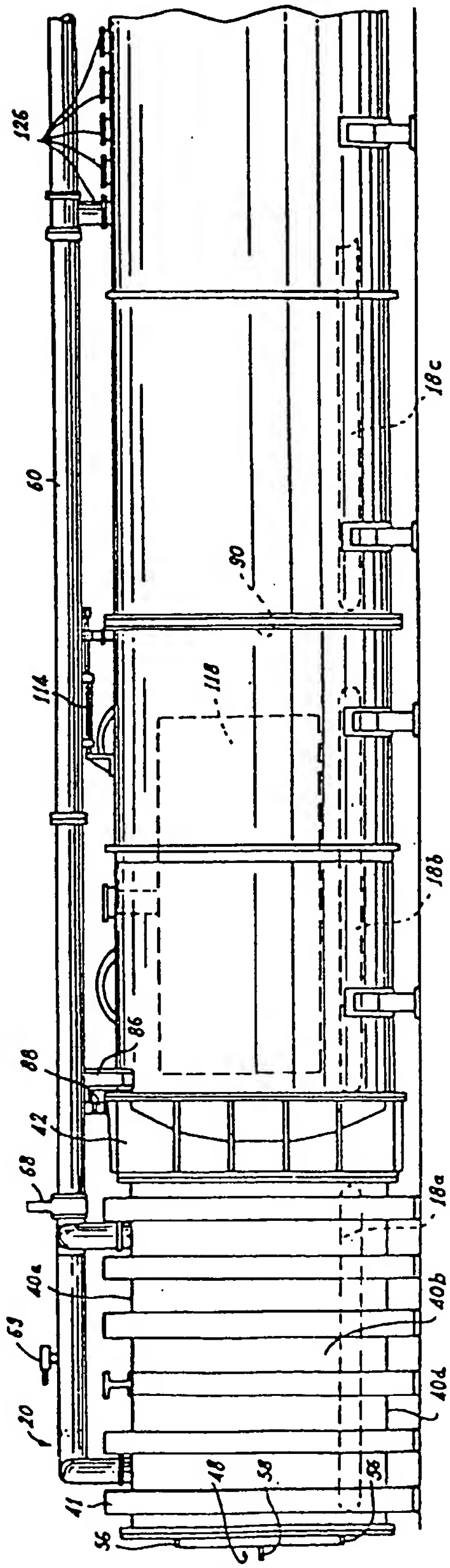
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Fig.4.

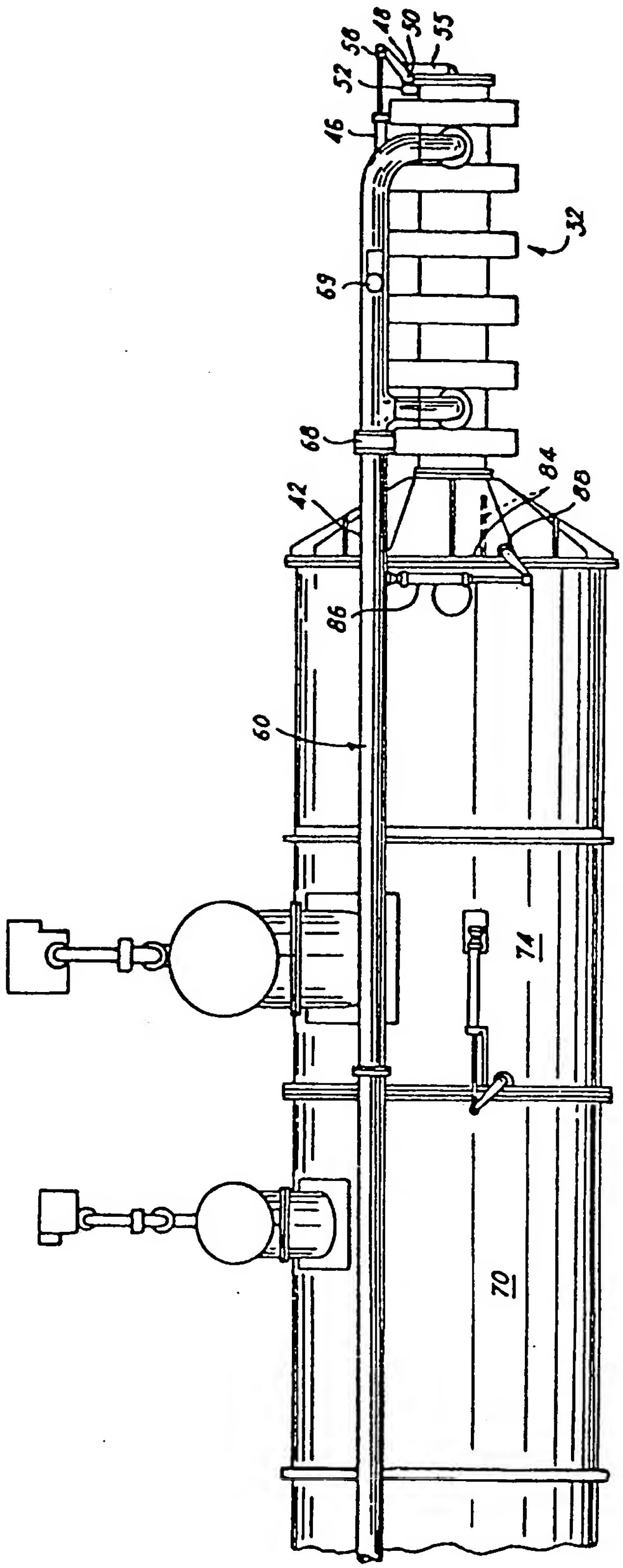

Fig.5.

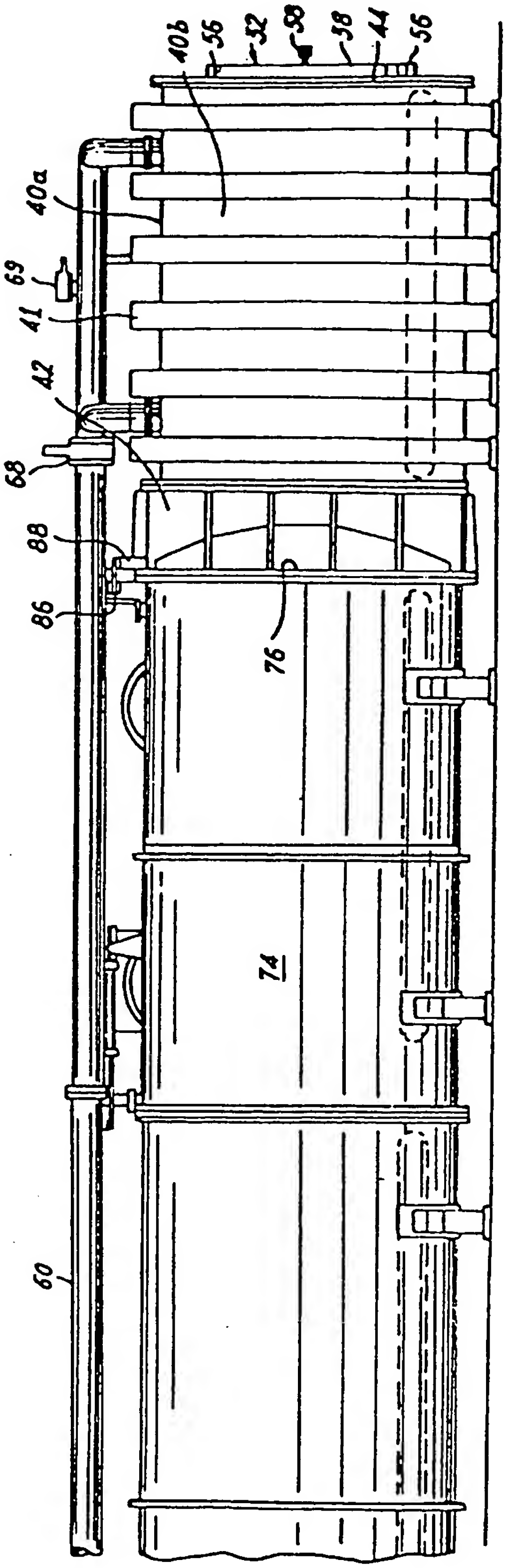

Fig.6.